RECOMMENDATION ITU-R M.1583[*]

Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites

(2002)

The ITU Radiocommunication Assembly,

considering

a) that, in some cases, the radio astronomy service and space services (space-to-Earth) have been allocated to adjacent or nearby frequency bands;

b) that the radio astronomy service is based on the reception of emissions at much lower power levels than are generally used in other radio services;

c) that, due to these low received power levels, the radio astronomy service is generally more susceptible to interference from unwanted emissions than other services;

d) that several footnotes to the Radio Regulations (RR) (such as Nos. 5.149, 5.340, 5.372 and 5.443B) draw attention to the protection of the radio astronomy service, particularly from spaceborne transmitters;

e) that due to the characteristics of non-geostationary (non-GSO) satellite systems, and in particular to the time-varying nature of interference, the level of interference from such satellites into radio telescopes cannot be evaluated in the same way as for GSO satellites,

recommends

1 that the calculation of unwanted emission levels produced by a non-GSO radionavigation-satellite service (RNSS) or a mobile-satellite service (MSS) systems on radio astronomy sites should be conducted by administrations using the method described in Annex 1;

2 that when performing these calculations, the antenna pattern described in Annex 2 should be used to model radio astronomy antennas;

3 that the percentage of time during which an equivalent power flux-density (epfd) level (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given an integration time) is exceeded should be calculated according to the method described in Annex 3.

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[*] This Recommendation should be brought to the attention of Radiocommunication Study Group 7.

ANNEX 1

Calculation of unwanted emission levels produced by a non-GSO RNSS or an MSS systems at radio astronomy sites

The methodology described here, based on the "equivalent power flux-density" (epfd) concept defined in RR No. 22.5C, is intended for use in calculating the power flux-density (pfd) levels produced by unwanted emissions of a non-GSO satellite system into radio telescopes, taking into account the characteristics of both the satellite system and the radio telescope antenna. The value of the epfd is the aggregate of the contributions from all satellite emissions expressed as the pfd of a single equivalent source on the boresight (peak of main beam) of the radio telescope.

1 Required parameters

Due to the particular characteristics of non-GSO satellite systems, it is clear that the level of the interference from such satellites into a radio telescope cannot be evaluated in the same way as for GSO satellites. A statistical approach is needed which takes into account the dynamic aspect of non-GSO satellites.

The evaluation of interference resulting from the satellites at the radio telescope during the integration time (2 000 s) should be based on statistical calculations and should take into account the parameters of both the satellites and the radio telescope.

Non-GSO satellite system parameters:

- the number of satellites visible in the sky at the radio astronomy station;
- the pfd at the radio telescope within the radio astronomy band considered, estimated using a dBsd or dBc mask;
- the distances between the satellites and the radio astronomy station;
- the detailed orbital characteristics of the satellites.

Radio telescope parameters:

- the antenna location;
- the antenna pattern and antenna gain;
- the practical range of pointing directions;
- the boresight pointing direction;
- the off-axis angles between the boresight of the antenna of the radio astronomy station and the directions of the transmitting satellites;
- the integration time (2 000 s).

2 Calculation of epfd levels at radio astronomy sites

The receiving gain of a radio telescope in the direction of a non-GSO satellite (as opposed to GSO) varies with time chiefly because of the movement of the satellite and the fine angular structure of the radio telescope's side-lobe pattern. There will be times when the telescope gain in the direction of a satellite is much higher than 0 dBi, and other times when it is less. In addition, in the case of multiple satellites of a non-GSO system, all their contributions must be included and properly taken into account.

This may be done using the concept of epfd originally defined to assess possible sharing conditions between GSO and non-GSO systems. In the section below the concept is developed for the case of a radio astronomy station subject to interference from non-GSO satellites. The definition is based upon RR No. 22.5C as adopted at the World Radiocommunication Conference (Istanbul, 2000) (WRC-2000).

2.1 Definition of epfd

When an antenna receives power, within its reference bandwidth, simultaneously from transmitters at various distances, in various directions and at various levels of incident pfd, the epfd is that pfd which, if received from a single transmitter in the far field of the antenna in the direction of maximum gain, would produce the same power at the input of the receiver as is actually received from the aggregate of the various transmitters.

The instantaneous epfd is calculated using the following formula:

$$epfd = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi \, d_i^2} \cdot \frac{G_r(\varphi_i)}{G_{r,max}} \right] \tag{1}$$

where:

N_a: number of non-GSO space stations that are visible from the radio telescope

i: index of the non-GSO space station considered

P_i: RF power of the unwanted emission at the input of the antenna (or RF radiated power in the case of an active antenna) of the transmitting space station considered in the non-GSO system (dBW) in the reference bandwidth

θ_i: off-axis angle (degrees) between the boresight of the transmitting space station considered in the non-GSO system and the direction of the radio telescope

$G_t(\theta_i)$: transmit antenna gain (as a ratio) of the space station considered in the non-GSO system in the direction of the radio telescope

d_i: distance (m) between the transmitting station considered in the non-GSO system and the radio telescope

φ_i: off-axis angle (degrees) between the pointing direction of the radio telescope and the direction of the transmitting space station considered in the non-GSO system

$G_r(\varphi_i)$: receive antenna gain (as a ratio) of the radio telescope, in the direction of the transmitting space station considered in the non-GSO system (see Annex 2)

$G_{r,max}$: maximum gain (as a ratio) of the radio telescope

$epfd$: instantaneous equivalent power flux-density (dB(W/m^2)) in the reference bandwidth at the radio telescope.

The epfd calculation in equation (1) assumes that the pfd due to all interfering sources is directed at the boresight of the receiving antenna, where the antenna gain is maximum. However, radio astronomy protection criteria are based on a 0 dBi contour of the radio astronomy antenna. Using the approach in equation (1), the pfd due to all interfering sources directed at the 0 dBi gain of the receiving antenna, can be determined as follows:

$$epfd_{G_r = 0\ \text{dBi}} = 10 \log_{10} \left[\sum_{i=1}^{N_a} 10^{\frac{P_i}{10}} \cdot \frac{G_t(\theta_i)}{4\pi\, d_i^2} \cdot G_r(\varphi_i) \right] \qquad (2)$$

The $epfd_{G_r = 0\ \text{dBi}}$ values resulting from equation (2), averaged over a 2 000 s integration time, can be compared with pfd levels (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given this integration time).

NOTE 1 – It is assumed that each transmitter is located in the far field of the radio telescope (that is, at a distance greater than $2D^2/\lambda$ where D is the effective diameter of the radio telescope and λ is the observing wavelength). Though this may not always be satisfied, it is considered to be an adequate approximation.

NOTE 2 – For some telescopes, the direction of maximum gain (boresight direction) may not always coincide with the geometrical axis of the radio telescope.

NOTE 3 – In the case of active antennas, P_i should be taken as the radiated RF power rather than the power at the input to the antenna.

NOTE 4 – The antenna gain of the transmitting station, $G_t(\theta_i)$ is taken at the frequency of the radio astronomy band considered. This may differ from the gain at the frequencies of the intended transmissions.

ANNEX 2

Model of radio telescope antenna pattern

Antenna patterns, such as the one described in Recommendation ITU-R SA.509, are not appropriate for use in a dynamic environment. In a dynamic environment, the model described in Recommendation ITU-R S.1428 is used for fixed-satellite service antennas. Further work is needed on the definition of radio astronomy antenna patterns. In the interim, and in the absence of measured patterns, the Recommendation ITU-R S.1428 patterns may be considered as representative of radio astronomy antennas, for both the main beam and side-lobe regions. The following example is extracted from Recommendation ITU-R S.1428 for the pattern for reflectors larger than 100 λ in diameter:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} (D\, \varphi/\lambda)^2 \quad \text{dBi} \quad \text{for} \quad 0° \le \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{dBi} \quad \text{for} \quad \varphi_m \le \varphi < \varphi_r$$

$$G(\varphi) = 29 - 25 \log \varphi \quad \text{dBi} \quad \text{for} \quad \varphi_r \le \varphi < 10°$$

$$G(\varphi) = 34 - 30 \log \varphi \quad \text{dBi} \quad \text{for} \quad 10° \le \varphi < 34.1°$$

$$G(\varphi) = -12 \quad \text{dBi} \quad \text{for} \quad 34.1° \le \varphi < 80°$$

$$G(\varphi) = -7 \quad \text{dBi} \quad \text{for} \quad 80° \le \varphi < 120°$$

$$G(\varphi) = -12 \quad \text{dBi} \quad \text{for} \quad 120° \le \varphi \le 180°$$

where:

$$G_{max} = 20 \log (D/\lambda) + 8.4 \quad \text{dBi}$$

$$G_1 = -1 + 15 \log (D/\lambda) \quad \text{dBi}$$

$$\varphi_m = 20\, (\lambda/D) \sqrt{(G_{max} - G_1)} \quad \text{degrees}$$

$$\varphi_r = 15.85\, (D/\lambda)^{-0.6} \quad \text{degrees.}$$

Alternately, a possibly more accurate representation for the innermost one degree of the pattern is given below, and may be used for this part of the antenna pattern.

1 Model of main beam

A realistic approach is to use the following model for the main beam of a circular antenna (see Note 1):

$$G_r(\varphi) = G_{r,max} \cdot \left[\frac{\mathrm{J}_1(2\pi x)}{\pi x} \right]^2 \tag{3}$$

where:

$$G_{r,max} = \left[\frac{4\pi\, A_{eff}}{\lambda^2} \right]$$ is the maximum gain (expressed as a ratio)

where:

$A_{eff} = \pi(D/2)^2$ is the area of the aperture of the telescope (m^2)

D: effective diameter of the telescope (m)

λ: wavelength (m)

$x = \dfrac{\pi \cdot D \cdot \varphi}{360 \cdot \lambda}$ with φ the off-boresight angle (degrees) and

$J_1(x)$: 1st order Bessel function.

The first null in this antenna pattern is at:

$$\varphi_0 = 69.88/(D/\lambda) \text{ degrees off-boresight}$$

For example, if $D = 100$ m and $\lambda = 3$ cm then $G_{r,max} = 1.09 \times 10^8$ (equivalent to +80.4 dBi), and:

$$\varphi_0 = 0.0209 \text{ degrees}$$

This main beam model corresponds to the ideal case of 100% aperture efficiency.

NOTE 1 – Equations (3) and (4) are expressed as a ratio.

2 Model of near side lobes up to 1° from the boresight

The following model is proposed for the near-in side lobes in the region $\varphi_0 \leq \varphi \leq 1°$ (see Note 1):

$$G_r(\varphi) = B \cdot \left[\frac{\cos(2\pi x - 3\pi/4 + 0.0953)}{\pi x} \right]^2 \tag{4}$$

where:

$x = \dfrac{\pi \cdot D \cdot \varphi}{360 \cdot \lambda}$ with φ the off-boresight angle in degrees

D: effective diameter of the radio telescope

λ: wavelength of operation

$B = 10^{3.2} \pi^2 ((\pi D/2)/(180 \cdot \lambda))^2$.

NOTE 1 – Equations (3) and (4) are expressed as a ratio.

ANNEX 3

Distribution of epfd levels

This Annex describes a way to derive epfd statistics over the whole sky.

1 Division of the sky into cells of approximately equal solid angle

The first step of this approach is to divide the sky into M rings parallel to the horizon and equally spaced in terms of elevation angle, from 0° to 90°. The width of each ring is $90/M$°. The next step is to divide these rings into cells whose azimuth width is chosen to provide an integer number of cells per ring and is approximately equal to:

$$\frac{90/M}{\cos(elevation)} \qquad \text{degrees}$$

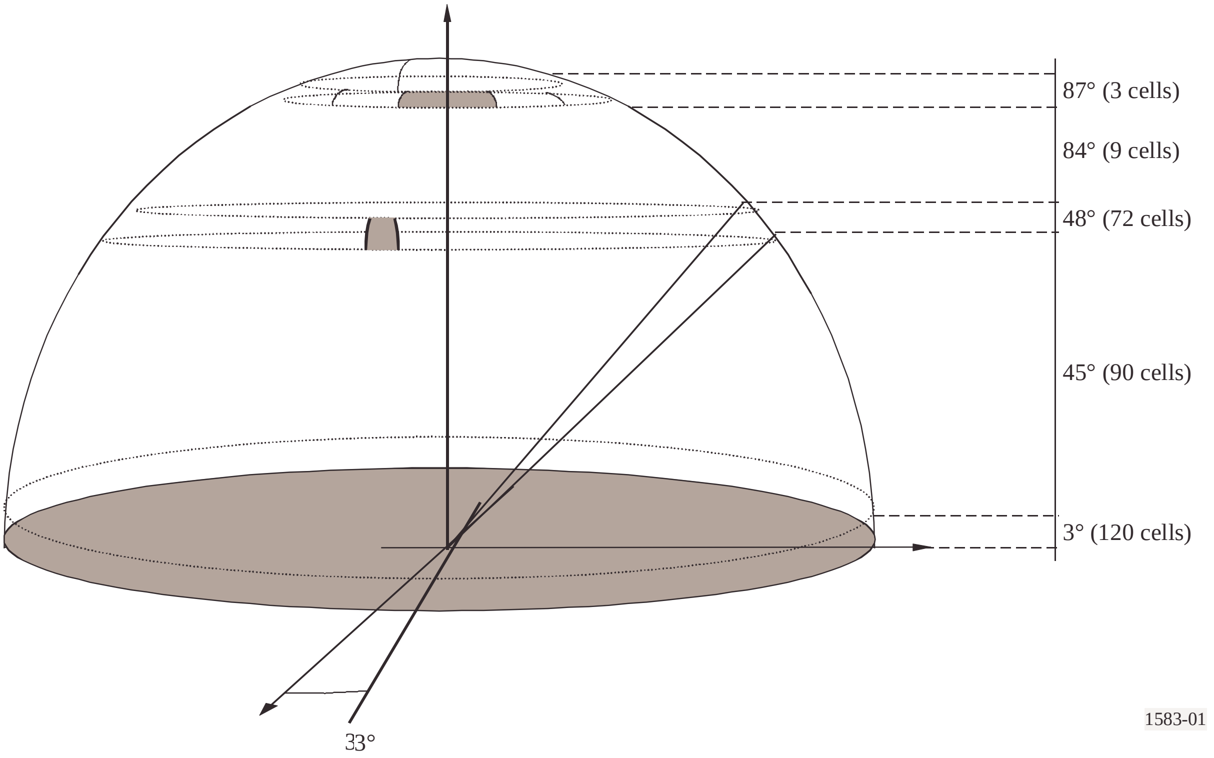
Figure 1 provides an example of division based on a step of 3° width in elevation, this divides the sky into 30 rings of 3° of elevation angle. Then, the azimuth width is approximately equal to:

$$\frac{90/30}{\cos(elevation)} \qquad \text{degrees}$$

Elevation is a mean elevation in a given ring.

FIGURE 1

Example of division of the sky in cells of approximately 9 square degrees of solid angle



This leads to a division of the sky into 2 334 cells of approximately 9 square degrees of solid angle each. Table 1 provides the number of cells for each ring corresponding to this example.

TABLE 1

Example of division of the sky into square cells of about 9 square degrees solid angle

Lower elevation of the ring (degrees)	Ring solid angle (square degrees)	Cumulative solid angle (square degrees)	Azimuth step (degrees)	Number of cells in the ring	Cell solid angle (square degrees)	Cumulative number of cells	Percentage of solid angle (%)	Cumulative solid angle (%)
0	1 079.51	1 079.51	3	120	9.00	120	5.23	5.23
3	1 076.55	2 156.05	3	120	8.97	240	5.22	10.45
6	1 070.64	3 226.69	3	120	8.92	360	5.19	15.64
9	1 061.79	4 288.49	3	120	8.85	480	5.15	20.79
12	1 050.04	5 338.53	3	120	8.75	600	5.09	25.88
15	1 035.41	6 373.93	3	120	8.63	720	5.02	30.90
18	1 017.94	7 391.87	3	120	8.48	840	4.94	35.84
21	997.68	8 389.55	3	120	8.31	960	4.84	40.67
24	974.68	9 364.23	3	120	8.12	1 080	4.73	45.40
27	949.01	10 313.24	3	120	7.91	1 200	4.60	50.00
30	920.75	11 233.99	4	90	10.23	1 290	4.46	54.46
33	889.95	12 123.94	4	90	9.89	1 380	4.31	58.78
36	856.72	12 980.66	4	90	9.52	1 470	4.15	62.93
39	821.14	13 801.81	4	90	9.12	1 560	3.98	66.91
42	783.31	14 585.12	4	90	8.70	1 650	3.80	70.71
45	743.34	15 328.46	4	90	8.26	1 740	3.60	74.31
48	701.32	16 029.79	5	72	9.74	1 812	3.40	77.71
51	657.39	16 687.17	5	72	9.13	1 884	3.19	80.90
54	611.65	17 298.82	5	72	8.50	1 956	2.97	83.87
57	564.23	17 863.06	6	60	9.40	2 016	2.74	86.60
60	515.27	18 378.33	6	60	8.59	2 076	2.50	89.10
63	464.90	18 843.23	6	60	7.75	2 136	2.25	91.35
66	413.25	19 256.48	8	45	9.18	2 181	2.00	93.36
69	360.47	19 616.95	9	40	9.01	2 221	1.75	95.11
72	306.70	19 923.65	10	36	8.52	2 257	1.49	96.59
75	252.09	20 175.74	12	30	8.40	2 287	1.22	97.81
78	196.79	20 372.53	18	20	9.84	2 307	0.95	98.77
81	140.95	20 513.49	24	15	9.40	2 322	0.68	99.45
84	84.73	20 598.21	40	9	9.41	2 331	0.41	99.86
87	28.27	20 626.48	120	3	9.42	2 334	0.14	100.00

2 epfd distribution for a cell

First, a random choice is made for a pointing direction of the radio astronomy service antenna which will lie within a specific cell on the sky as defined in § 1. Then, the starting time of the constellation is randomly chosen. The epfd is then evaluated for each time sample over a 2 000 s integration time. The average epfd corresponding to this trial is then calculated for the chosen pointing direction and starting time of the constellation.

This operation is repeated to obtain a statistical distribution of the epfd in the considered cell. The methodology involves a number of trials, each of which calculates the averaged epfd level over a 2 000 s integration interval. The greater the number of trials, the more accurate this distribution will be. A sufficient number of trials is needed to achieve the required confidence level in the results. In particular, the number of trials multiplied by the 2 000 s integration time should be significantly higher than the period of the constellation. It is also necessary to ensure adequate statistical sampling over the full period of the constellation. Once it is found that no further significant change occurs in the distribution, it can be concluded that a sufficient number of trials has been performed. This check can be done either automatically as an integral part of the simulation, or manually, by stopping the simulation at regular intervals.

3 epfd distribution in worst-case pointing directions (to be applied only if the pfd levels from satellites are constant for a given elevation angle of a radio astronomy service antenna)

The evaluation of the epfd distributions in cells on the sky may be simplified by first evaluating the epfd distribution in pointing directions corresponding to worst-case pointing directions. These worst-case pointing directions may be taken as those pointing directions where the probability of visibility of satellites is the highest. These pointing directions may be determined according to Recommendation ITU-R S.1257 – Analytical method to calculate short-term visibility statistics and interference statistics for non-geostationary satellite orbit satellites as seen from a point on the Earth’s surface, (equations (28) and (29)). For a given elevation angle and a given constellation of non-GSO satellites, this Recommendation allows the calculation of the worst-case azimuths (there are usually two worst-case azimuths at a given elevation).

For the cells within which these worst-case pointing directions lie, the epfd distribution may be evaluated for a sufficient number of 2 000 s integration times. Then, this epfd distribution may be compared with a pfd threshold level (defined assuming a 0 dBi receiving antenna gain in the direction of interference and given a 2 000 s integration time).

For a cell, the percentage of time during which a pfd threshold level is exceeded can be calculated as the percentage of 2 000 s integration periods in which the average pfd at the radio telescope exceeds this pfd threshold level.

Comparison of the epfd distribution with the pfd threshold level for cells corresponding to these worst-case pointing directions, can provide the following conclusions:

– If, in all the *M* rings, the pfd threshold is met in the worst-case pointing directions, during a percentage of time higher than the percentage of time criterion, this means that the criteria will be met over the whole sky.

– If, in a ring defined for a given elevation angle, the pfd threshold is met in the worst-case pointing directions, during a percentage of time higher than the percentage of time criterion, this means that the criteria will always be met for the corresponding entire ring.

– If the interference criteria are not met, then further investigation is needed.

The consideration of these worst-case pointing directions provides information on the location of worst-case cells.

4 Output in terms of epfd distribution

The epfd calculation described in § 2 provides a distribution of epfd levels for each cell of the sky as shown in Fig. 2.

FIGURE 2

Example of a cumulative epfd distribution for a cell